Dual adaptive optics system for laser processing of diamond

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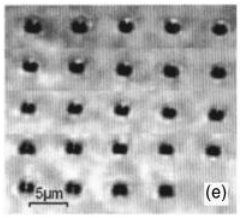
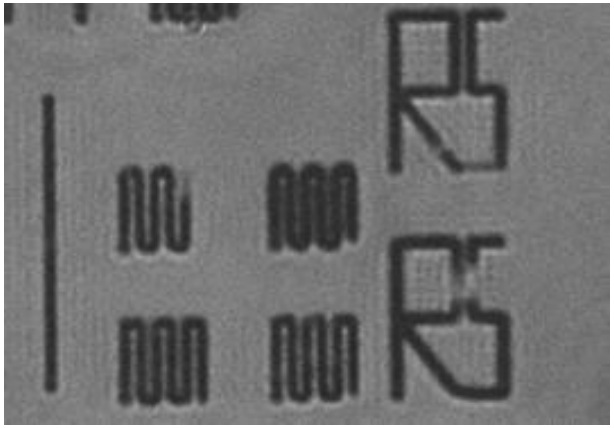
Diamond uses

- Diamond can be fabricated for use as:
  - Photonic crystals



Zhou et al. Appl. Phys. Lett. 87, 2005

  - Colour centres for quantum information processing
  - Waveguides?
  - Circuitry?

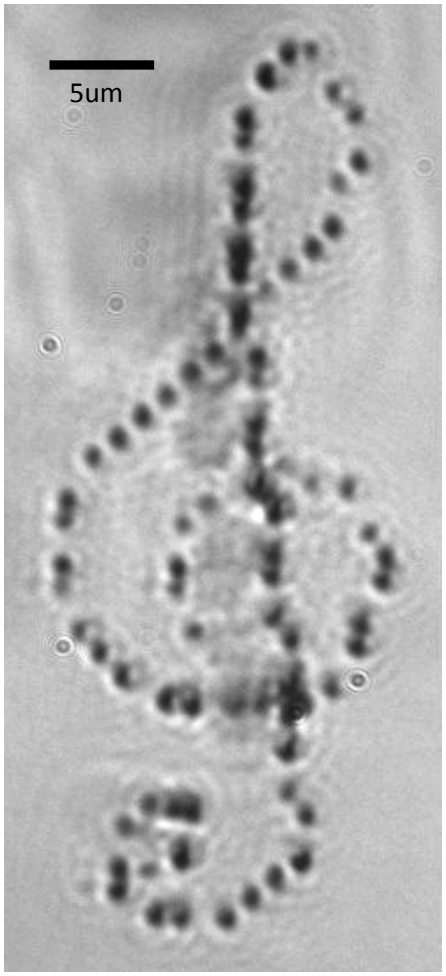


Top view

20μm nominal depth

Diamond fabrication

- How?
  - Femtosecond pulsed laser
  - Graphite-like phase created



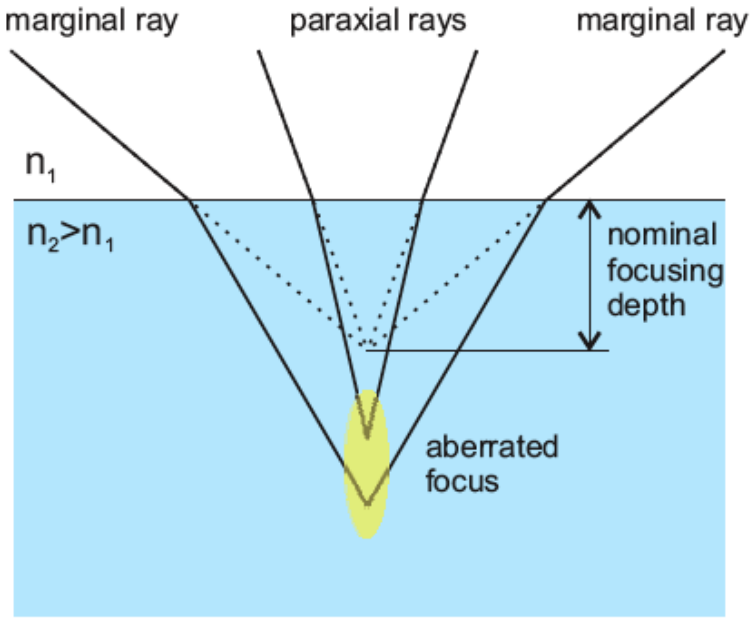
Top view

Nominal depth 80µm

Pulse energy 1.35µJ

Diamond fabrication

- Problems
  - Refractive index mismatch
  - Distorted focus
  - Fabrication reliability proportional to focal spot quality
  - High NA lens required, exacerbates problems



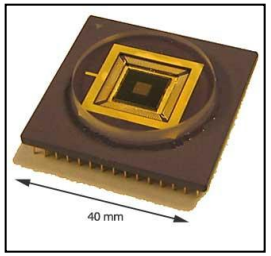
Adaptive optics

- Pre-aberrate and correct wave fronts using adaptive element
  - Spatial light modulator (SLM)

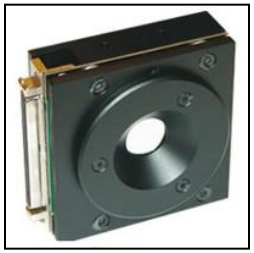
Hamamatsu

  - Deformable mirror (DM)

OKO Technologies



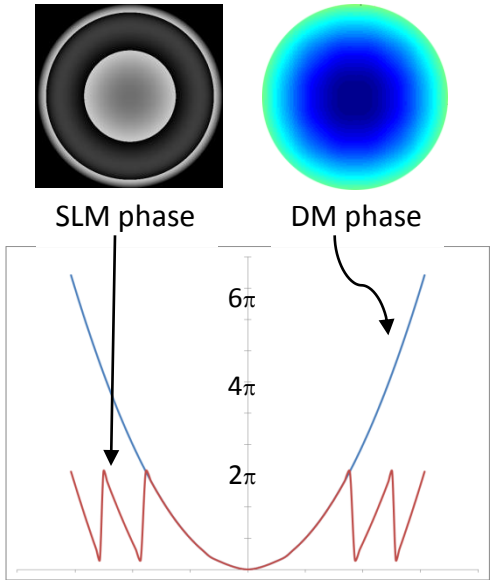
Boston Micromachines



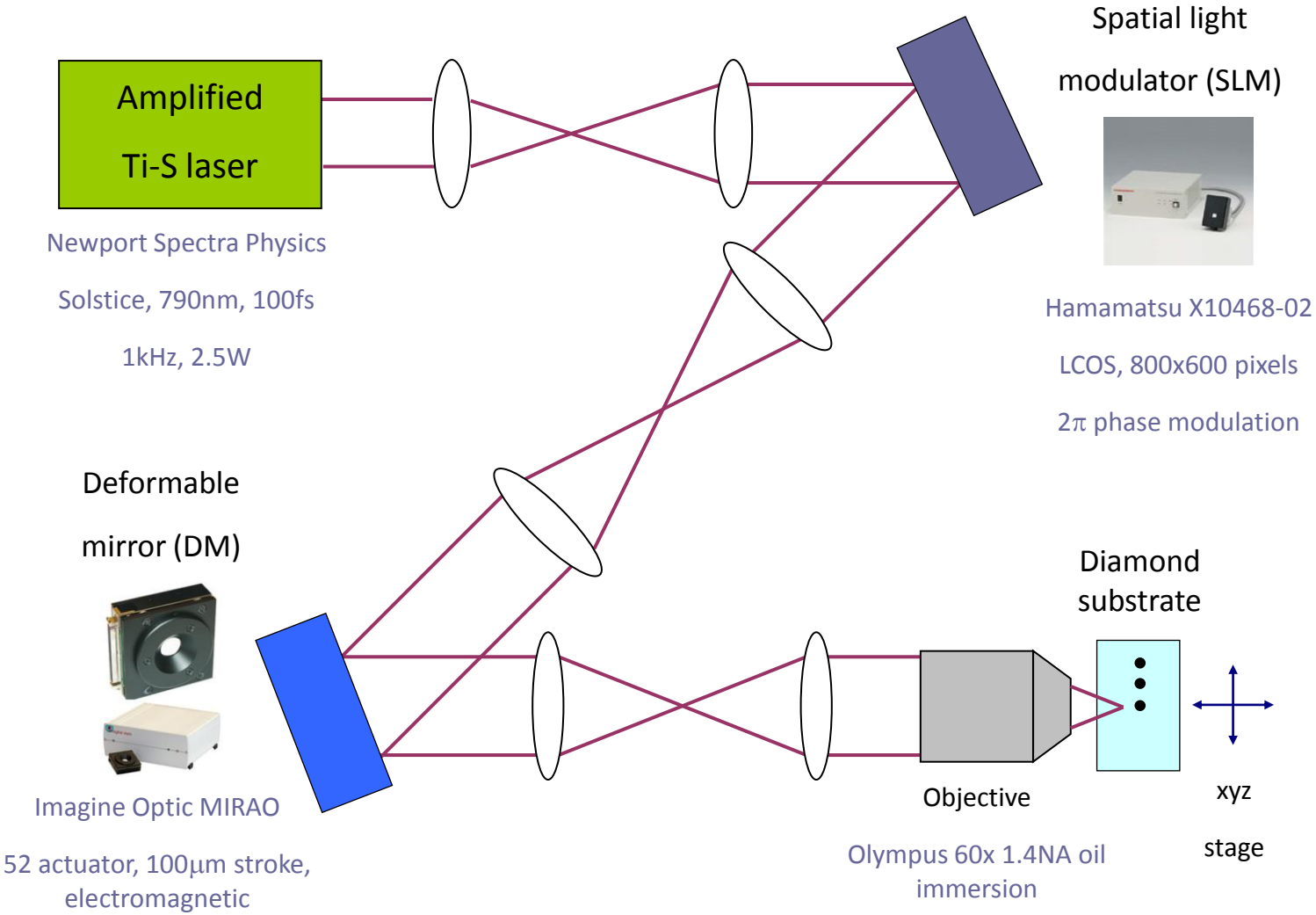
Imagine Optic

Adaptive optics

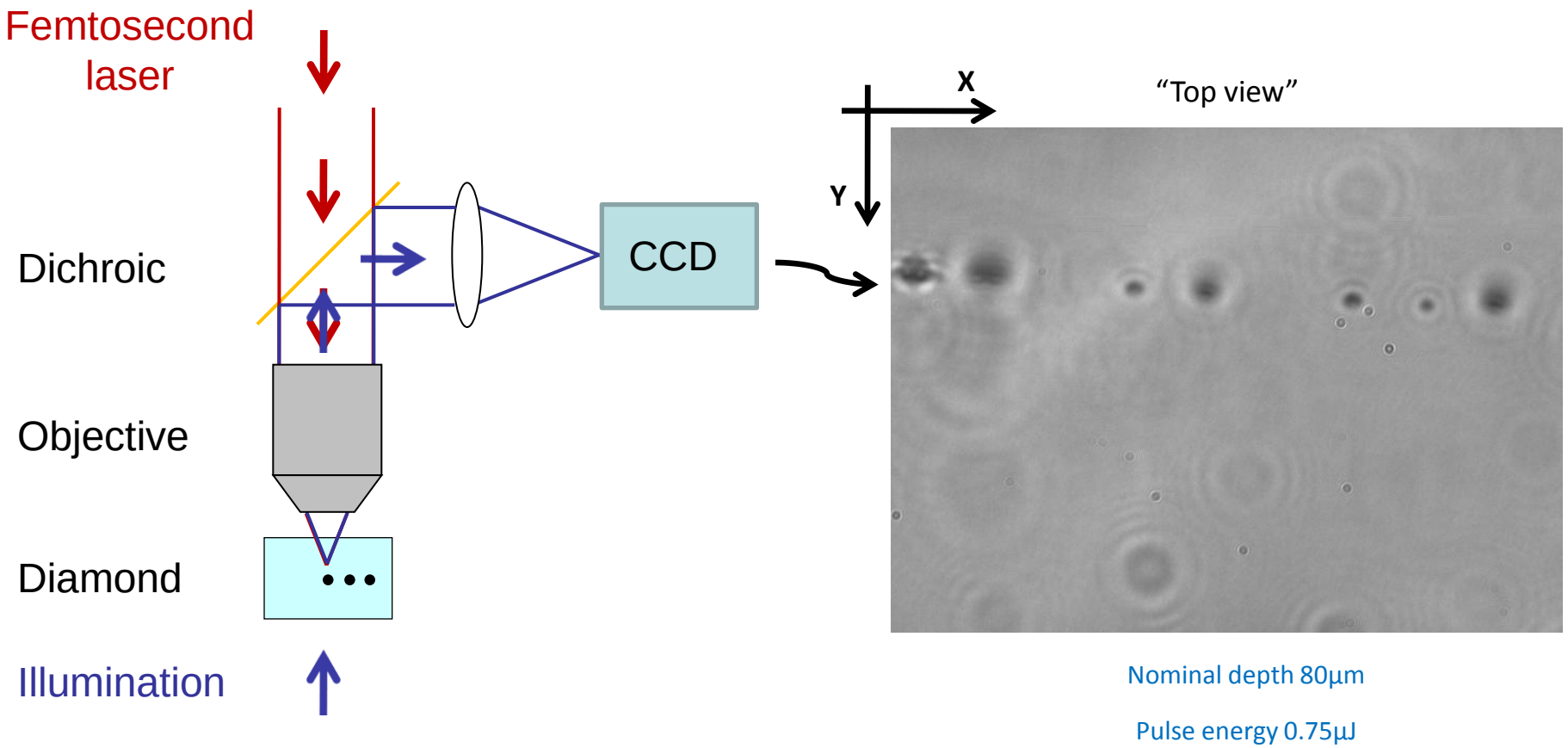
- SLM
  - – Limited phase range
  - \+ Large amplitude, complex phase pattern
  - – Phase wrapping not perfect
- DM
  - \+ Very large correction range (≈100λ)
  - – Accuracy limited
  - – Precision limited
- Dual correction



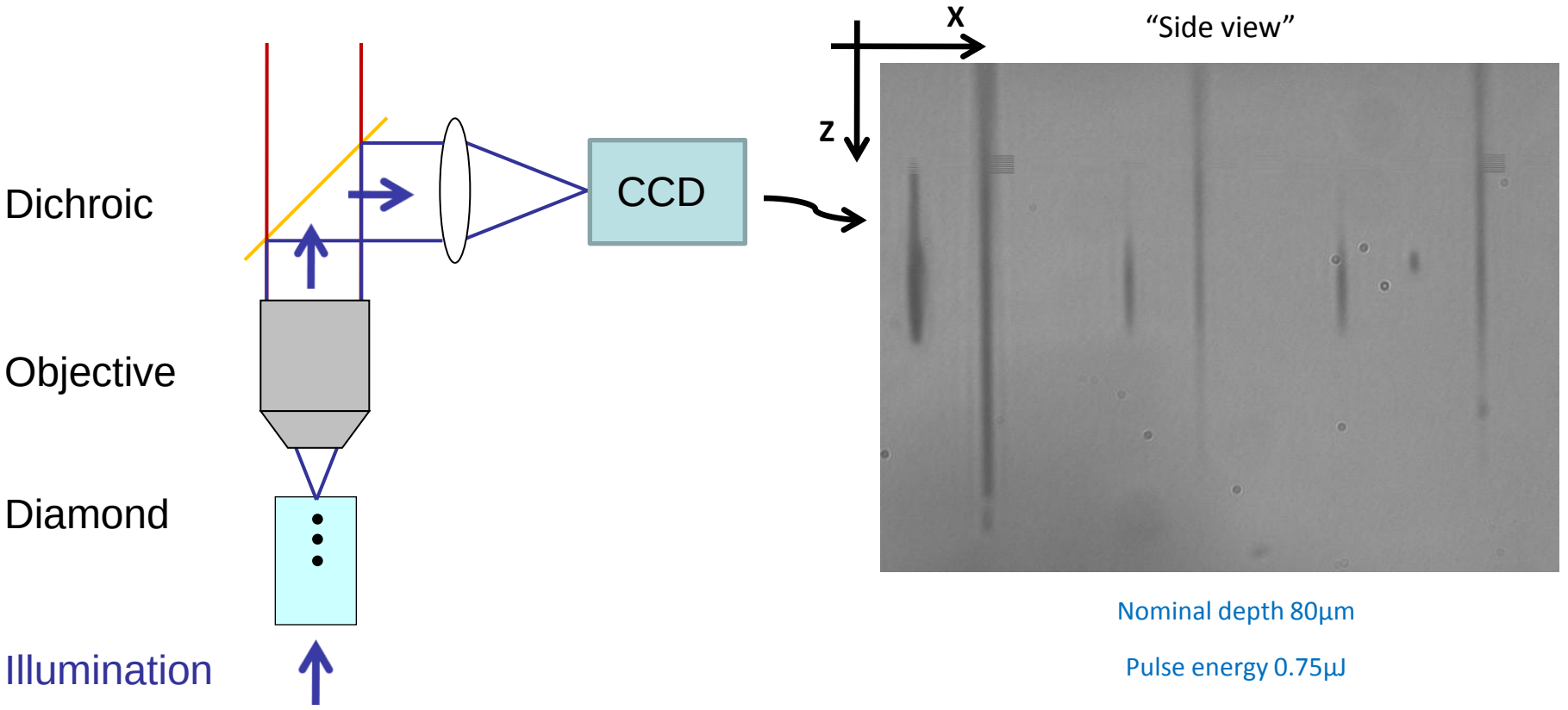
Dual adaptive optics



Dual adaptive optics

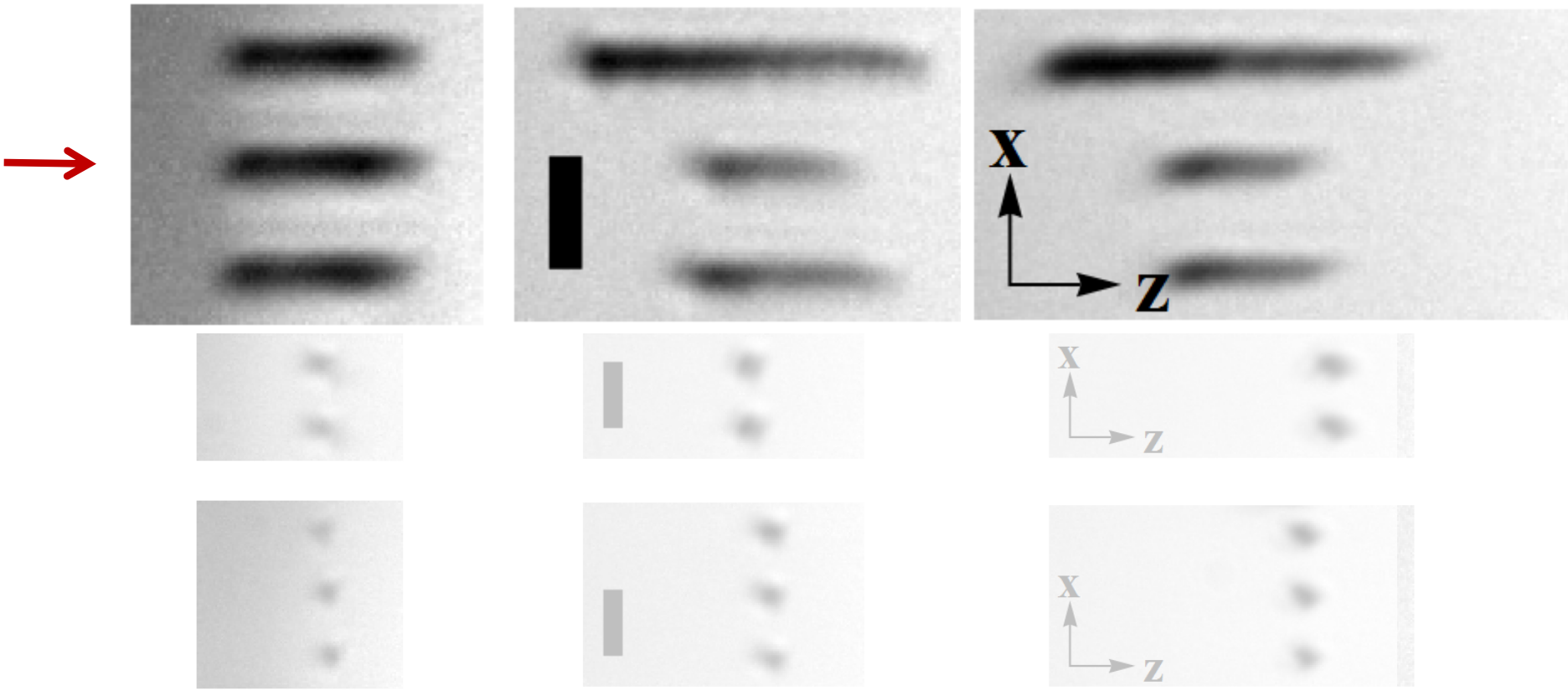


Dual adaptive optics



Fabrication

- No aberration correction



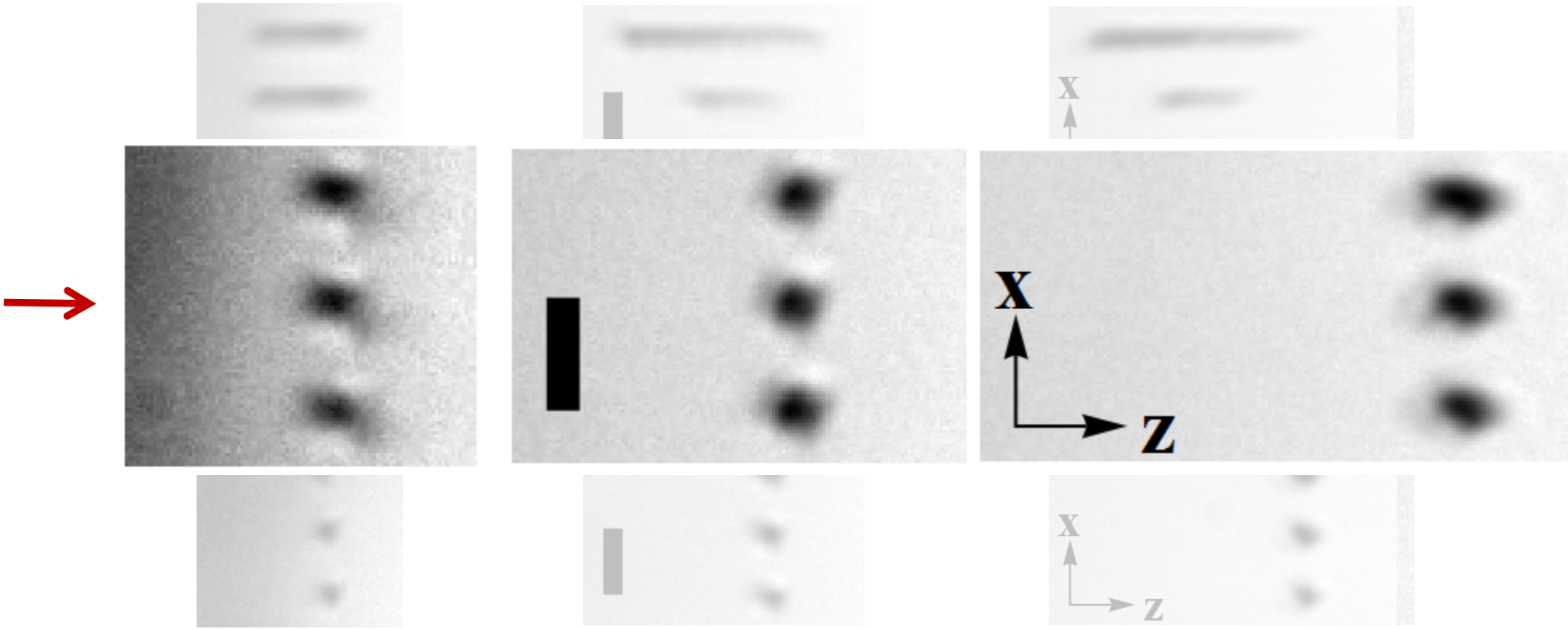
40µm actual depth

80µm actual depth
Scale bar 5µm

130µm actual depth

Fabrication

- SLM only aberration correction



40µm actual depth

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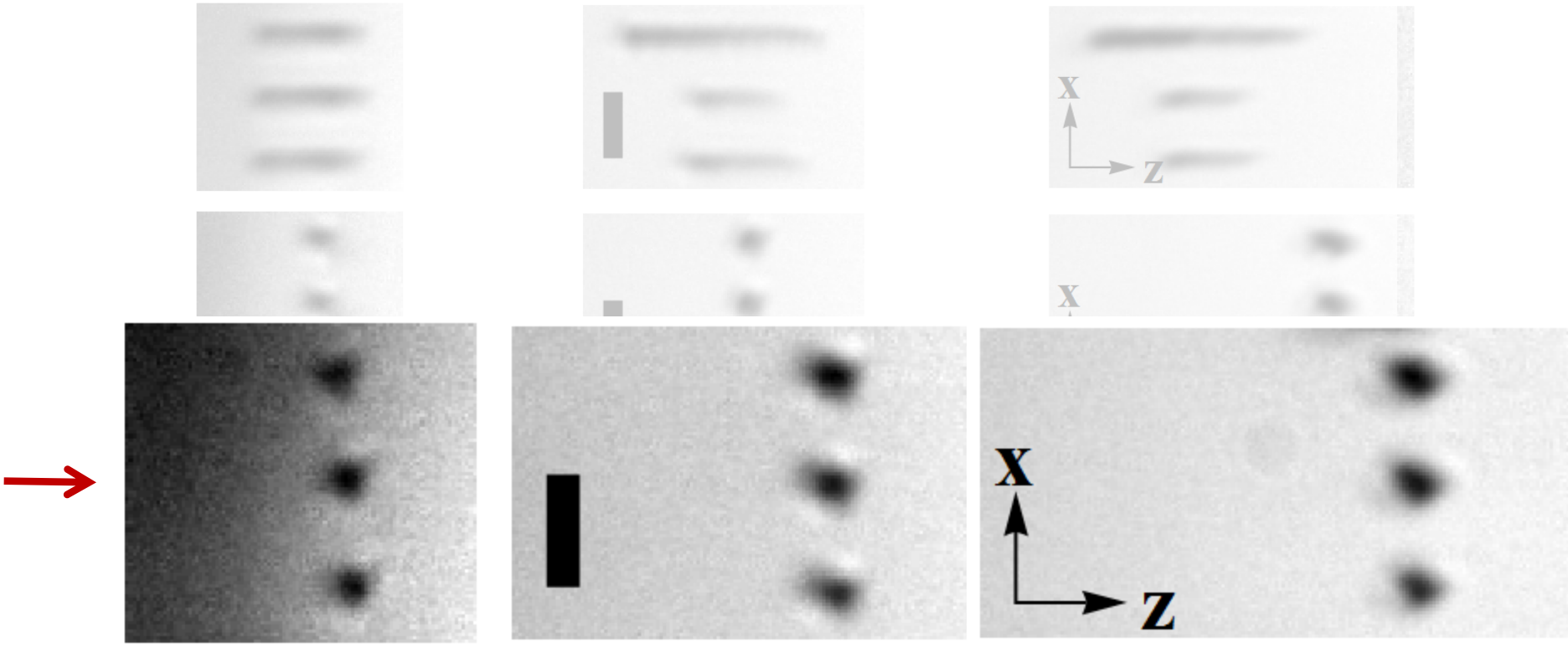
Scale bar 5µm

130µm actual depth

Fabrication

- Dual aberration correction



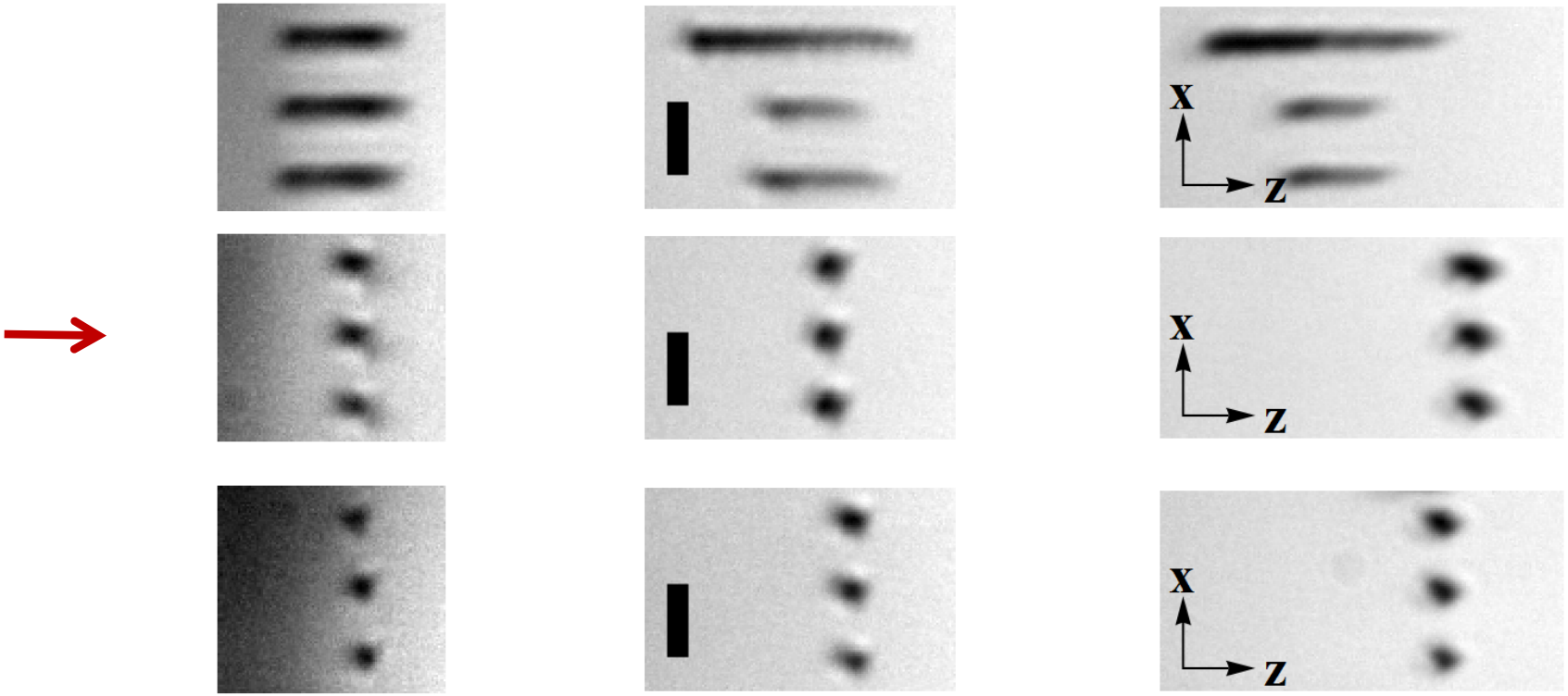
40µm actual depth

80µm actual depth
Scale bar 5µm

130µm actual depth

Fabrication

- No (top) / SLM only (middle) / dual (bottom) aberration correction



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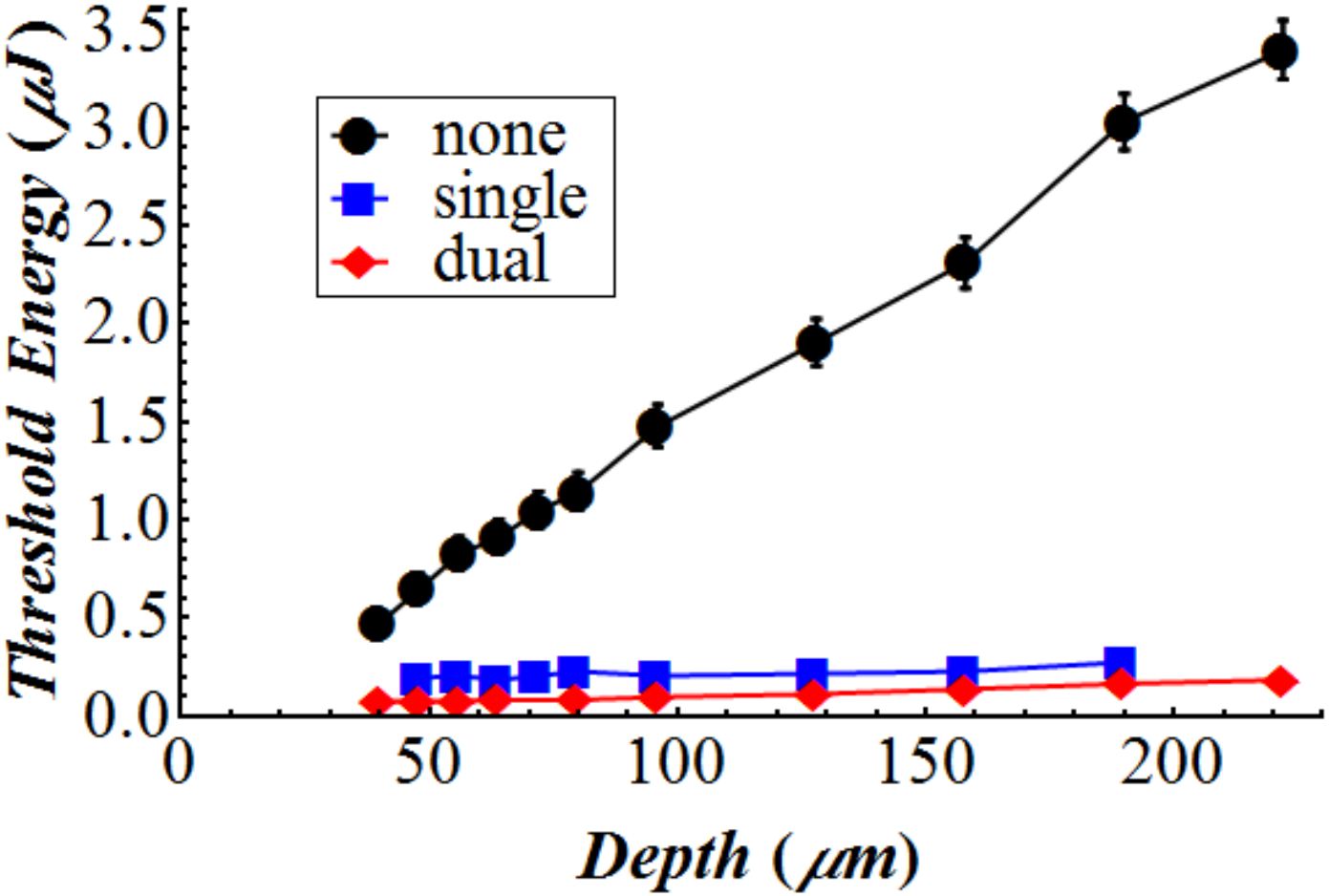
Scale bar 5µm

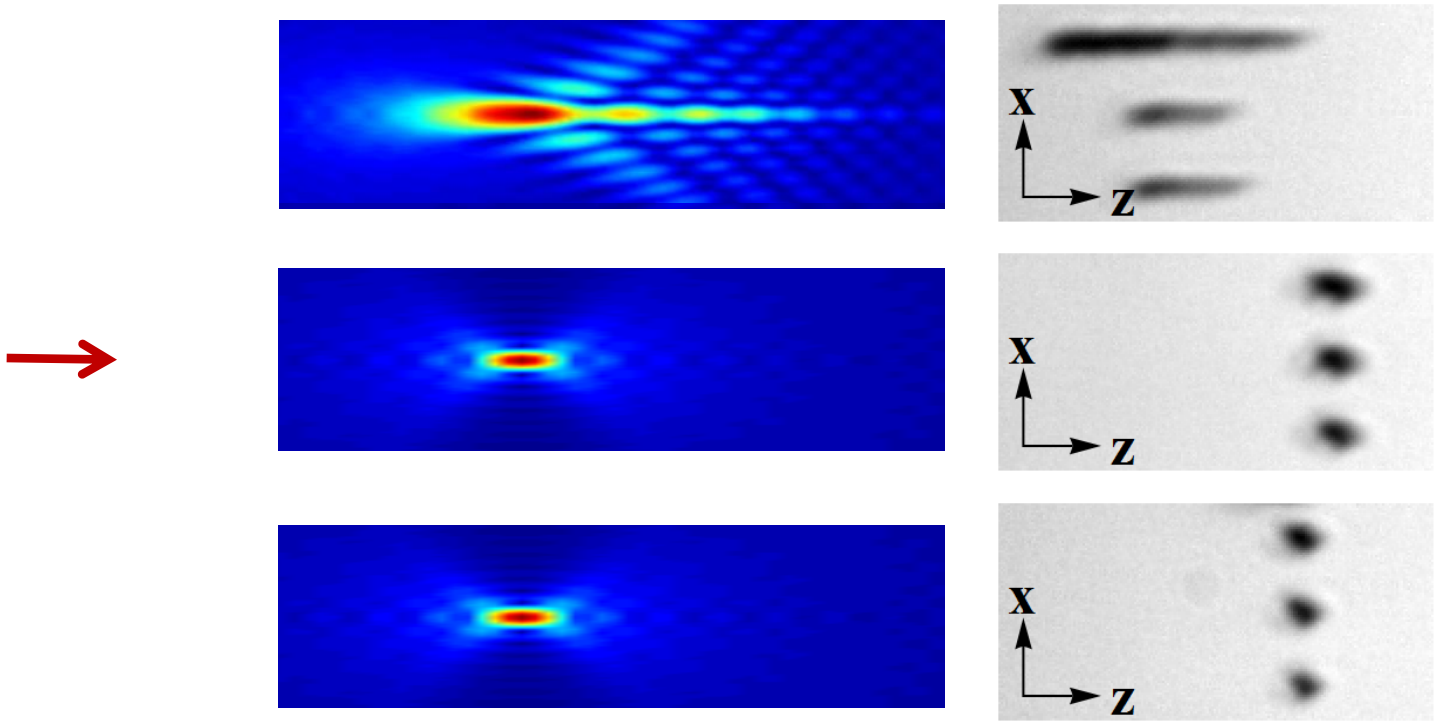
130µm actual depth

Dual adaptive optics



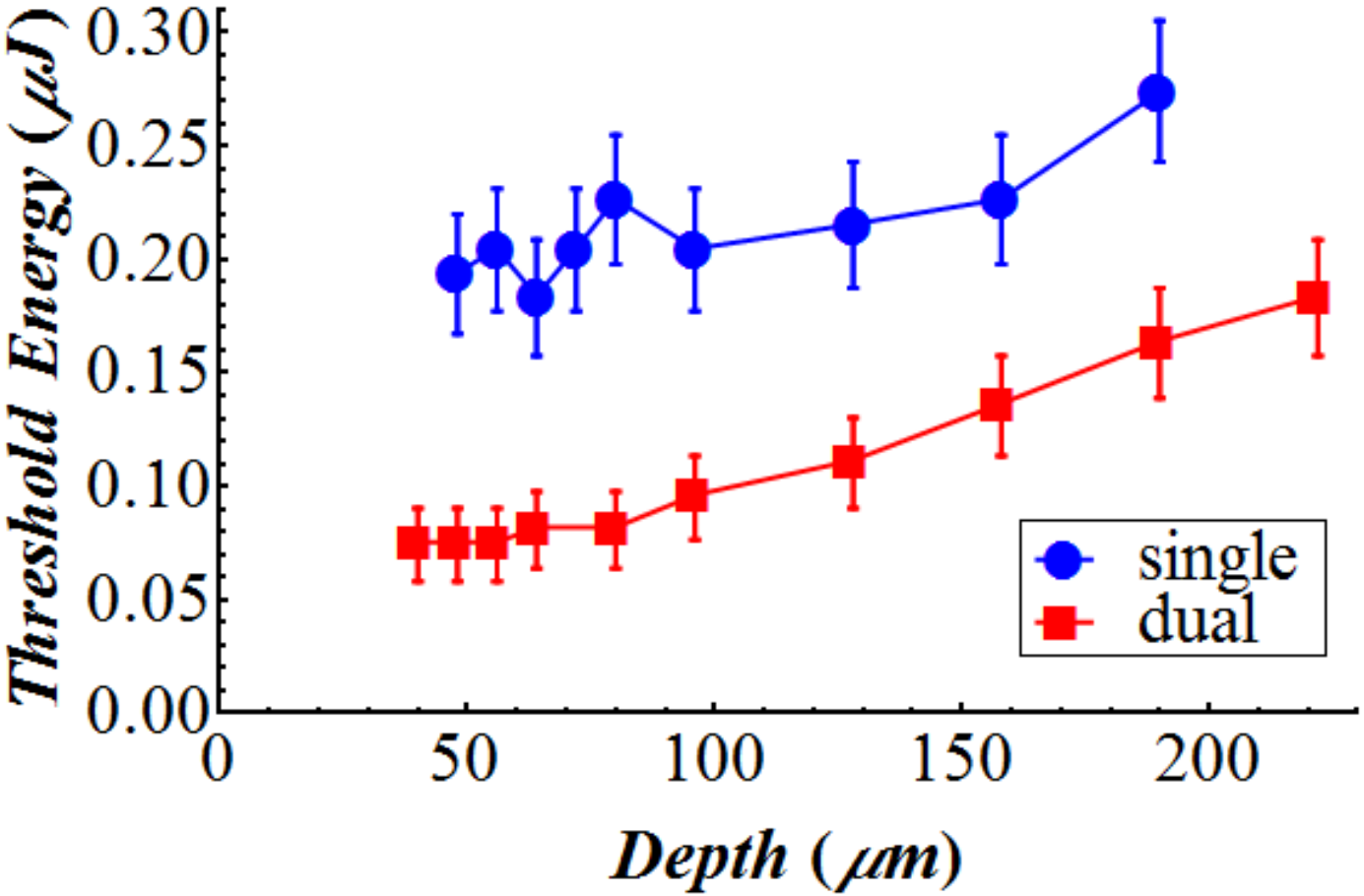
Fabrication

- No (top) / SLM only (middle) / dual (bottom) aberration correction



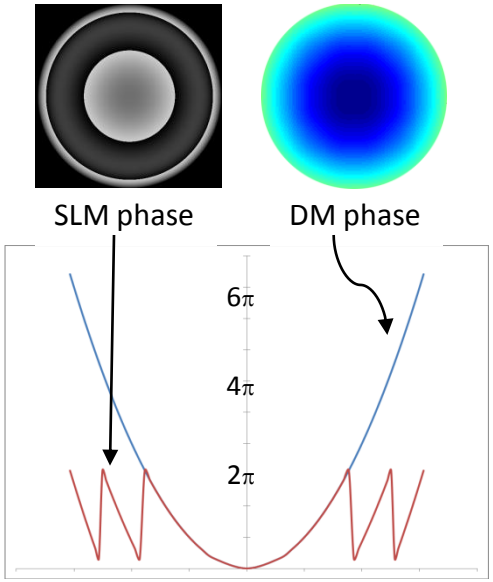
130µm actual depth
Scale bar 5µm

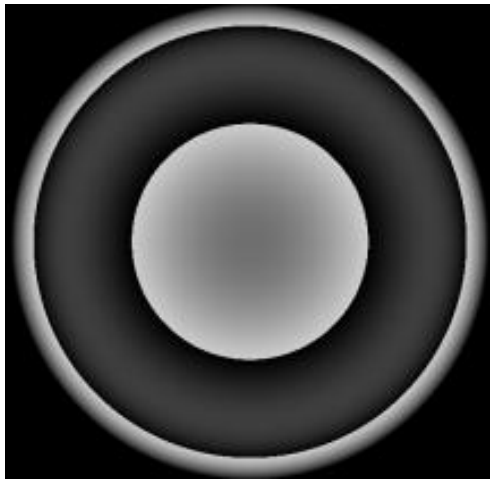
Dual adaptive optics

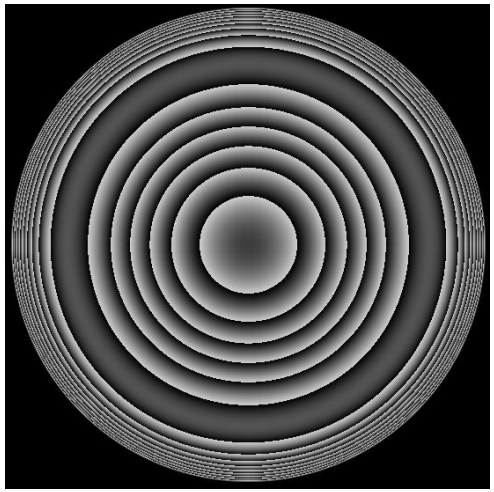


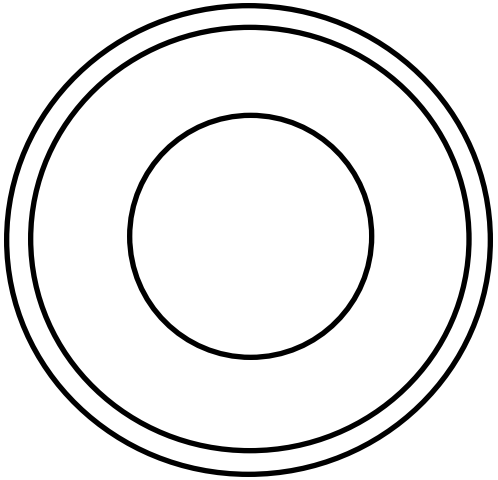
SLM Deficiencies

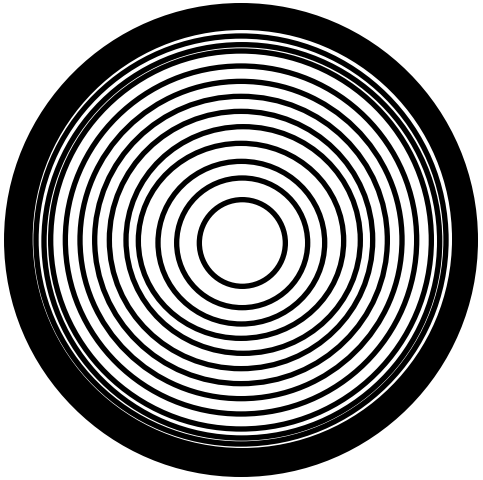
- Light loss at phase wraps





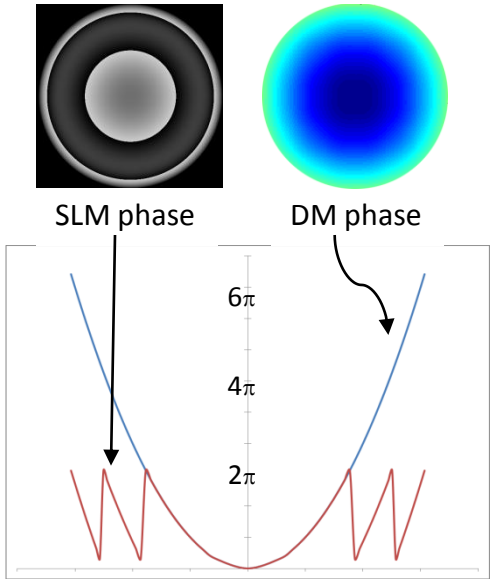




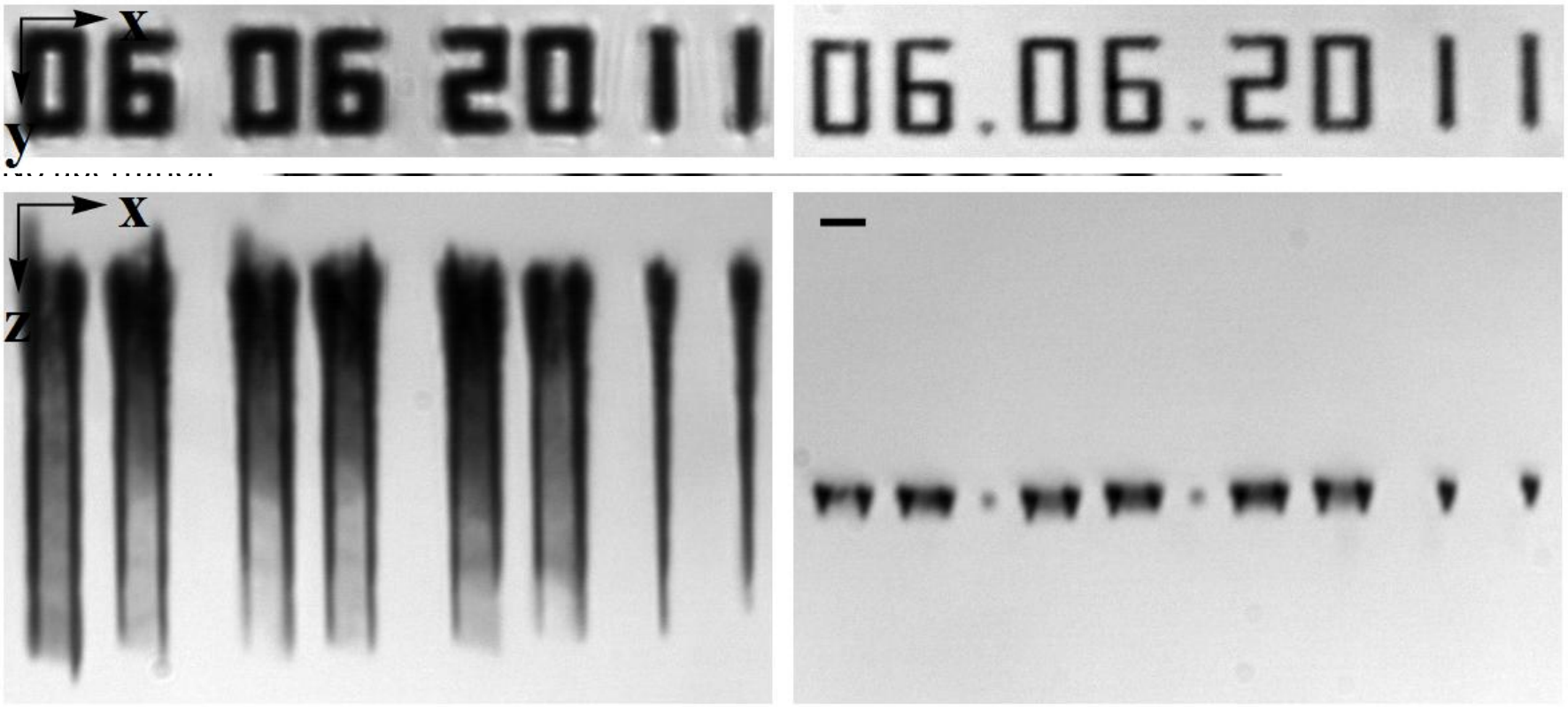


SLM Deficiencies

- Optical path length not corrected

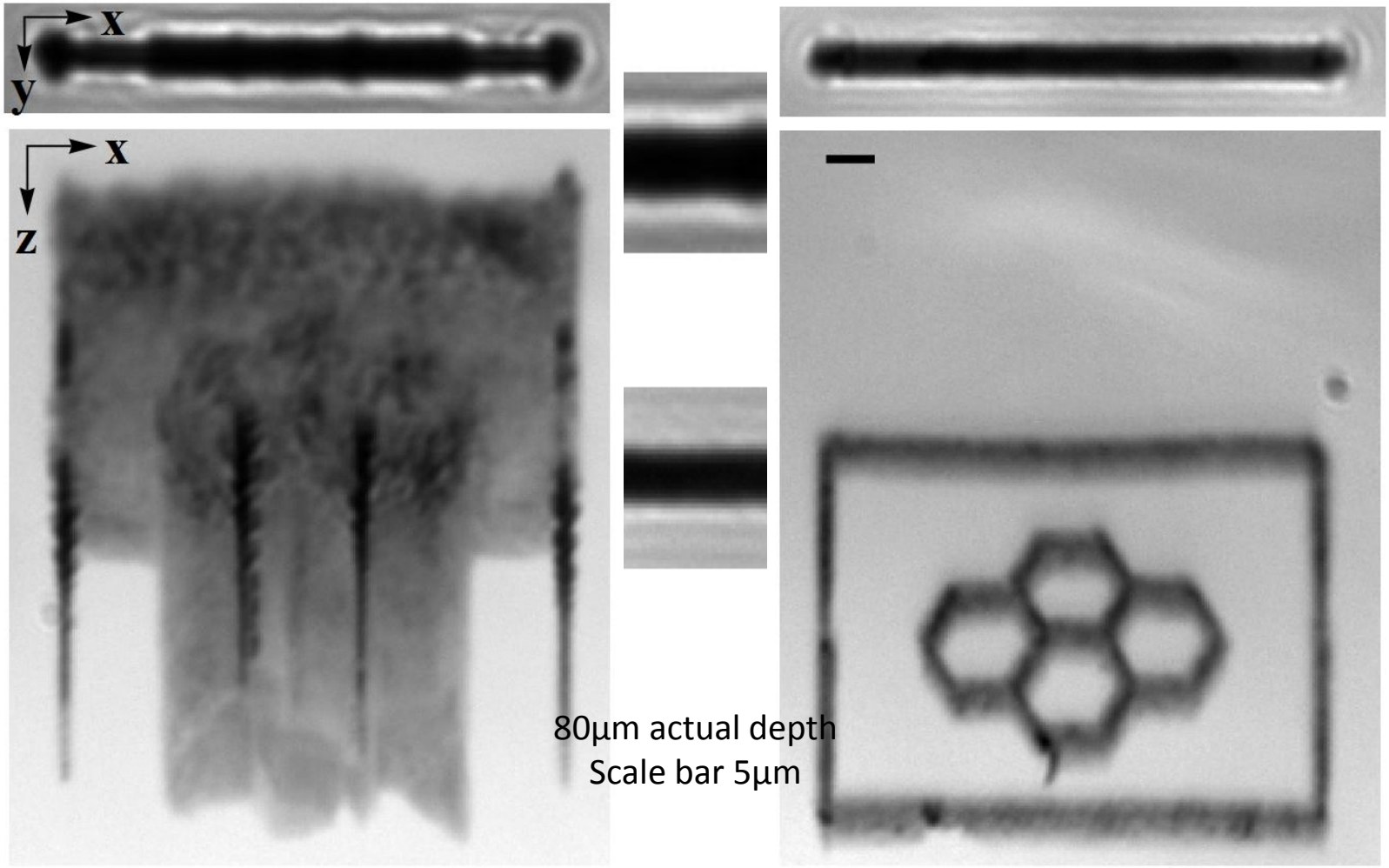


Fabrication of extended structures



80µm actual depth
Scale bar 5µm

Fabrication of extended structures



Conclusions

- Fabrication without aberration correction shows broad, elongated features.
- Compact graphitic structures have been fabricated deep in the bulk of diamond using a femtosecond laser and a dual adaptive optics setup, consisting of a SLM and DM, to correct for depth dependent aberration.
- Adaptive aberration compensation was shown to be crucial for maintaining controlled fabrication, allowing micron-scale structures to be fabricated down to depths greater than 200 mm.
- Sharing the load of the aberration between the two adaptive elements led to increased fabrication efficiency compared to using the SLM alone.

Acknowledgements

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